Integration of reliability in the design process, a case study of a submersible pump

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Abstract— The current context of increased competition in the industrial world has led it to change its view of the performance for now move towards a global vision of the entire life cycle of systems. To achieve this goal, it is necessary to cause changes in the methods of design maintenance to streamline its overall cost over the life of the system.
This paper proposes an approach and tools that allow the designer to understand the mechanisms of failure components of the product in order to reduce their impact on the conduct of the latter, and finally to assess the probability of failure or operation. To demonstrate the value of our study, we conducted a case study on a submerged for the sake of Small and Medium Enterprises (SMEs) Moroccan.

Keywords— Performance, design, maintenance, reliability, life cycle.

1. Introduction

Changing needs and fierce competition mean that companies should review their process of development and marketing of their products. Resource mobilization, innovation, reduced time to market, reducing prices, improving product quality and service, the elimination of all sources of waste are all requirements to take into account at the design stage. [15]
On the other hand an effective reliability program is a series of tasks to be implemented throughout the life cycle of the product. Usually, the activities of the reliability of self-employment in engineering projects [12], and methods for integrating different assessment of the reliability in the process design tools are poorly defined. What makes it difficult for the designer to pre- validation, a priori reliability, before moving on to a later phase of the design process. This generates an accumulation of errors in each phase of the process, and these have a direct impact on the time required for the validation of a product and therefore the total cost of development and marketing.
To contribute to the success of projects from the point of view of reliability in the early stages of design, minimizing the number of changes necessary to meet customer requirements and thus reduce the time required during the validation of a product, we propose a methodology for pre- validation of reliability to adopt in the first phase of the process. This methodology includes the main design phases and tasks that must be in each phase, as well as tools to help achieve these tasks.

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2. Definitions

2.1 Design Process.

There are several practices and approaches in design, but we found a common frame design activities [13]:
- Understanding and defining customer needs;
- Definition of the main problem to solve;
- Specification of the solution;
- Optimization of the proposed solution by performing analyzes;
- Verify the design obtained, to see if it meets the initial requirements of the client.

In what follows, we describe the model that has been most successful in the European school of design, but also the most accepted internationally [10].
This model is based on the systematic approach described by Pahl and Beitz [6]. Referring to the work of Pahl and Beitz [6], the design process is divided into four main phases [6]. Each phase is broken down into several stages of work and specific tasks.

2.2 Reliability

The reliability R (t) is the characteristic of a system expressed by the probability that perform the function for which it was designed, in given conditions for a given [5] length. And according to [6] confidence is the characteristic of a system expressed by the probability that perform the function for which it was designed, in given conditions for a given time instance, the lifetime of a system is used to measure the quantity of the service provided. Generally, the lifetime of a system is measured by the number of hours that he actually work [4] .

3. Model taking into account reliability in the design process.

3.1 Planning phase and identification of needs.

At the planning stage, the tasks of reliability must allow multiple client expectations, establish requirements for competitive reliability, build a team and provide the resources needed for a reliability program can be done under the best conditions (Figure 1). Reliability tasks in this phase of the design process are briefly explained below.

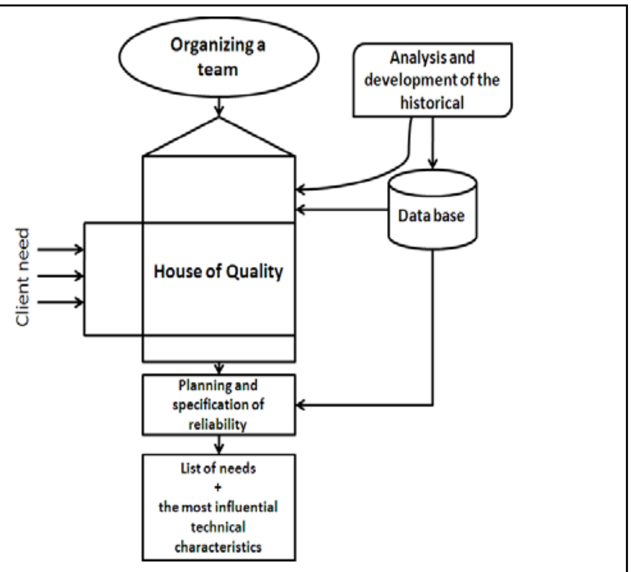

Fig.1 Phase planning tasks.

Establishment of a team of reliability. A multidisciplinary team with recognized expertise in various technical, economic areas expertise ... must be assembled at the beginning of the planning stage of the product so that the reliability requirements are taken into account in the decision making process . The solution proposed by the team can be maximized if the team members have diverse expertise, such as: reliability, market research, design, testing, manufacture and operation in the field.

Analysis and evaluation of the historical reliability (if available). This task is to collect, collate and analyze customer feedback, test data and insufficient product data prior generation. The analysis should indicate the items the customer was not satisfied and reveal the different areas for improvement. A recommended characterization data model was developed by Robert Klein, Cohen [9], and can be operated in achieving this task.

Quality Function Deployment (QFD). When performing this step, it will reduce all the technical characteristics affecting the reliability, focusing on the customer's expectations in terms of reliability, and assigning an important note . Then these specifications will be highly correlated to identify the various contradictions and get those that affect product reliability. The technical characteristics selected to be developed at a lower level with more importance.

Stevenson [16] and Heizer & Render [7] detail the quality function deployment. These houses are in the order of the build quality to better meet customer expectations. The first house is on the technical characteristics of the following components and the production process and finally the quality project.

Planning and specification of reliability. The objective of this task is to establish a goal of competitive reliability that is economically feasible, and develop an effective program of reliability to meet or exceed the threshold. This task can be facilitated by using the results of the analysis of QFD and available databases previously collected.

This phase results in a specification of requirements and identifying the most important technical features and their target values . These characteristics must be deployed in the following phases and serve as control factors in the design process.

3.1.1 Application.

In order to apply our approach to the submerged pump Moroccan SMEs, we follow the steps below:

1) We realize a statement of customer requirements to define entries quality home. These expectations are often blurred and non-technical. For the system studied, the expectations of the customer are:
   - High reliability,
   - Minimum operating noise,
   - Maximum flow: 65 m^3 / h
   - Manometric maximum: 350 m
   - Maximum diameter of the pump: 160 mm
   - The yield was approximately 60-70%.

NB Total manometric heights provided by a submersible pump cannot exceed a few tens of meters. To overcome these values multistage centrifugal pumps where several wheels are mounted in series on the same tree are used. The discharge of pump communicates with a suction pump in the following.

These requirements are listed in the entries "WHAT" quality home.

2) We determine the appropriateness of the client, with interest for each requirement compared to other rates. Various approaches to scale are used in practice, but none of it is theoretically good. Overall pump - turbine , we use the analytic process approach , Armacost [14], whose rate the level of importance is given on a scale of 1 to 9: 9 being given as an extremely important level 7 as highly important, 5 as very important, 3 as important and 1 as not important . The values 2, 4, 6, and 8 are assigned to a level of importance between the two.
   For a consideration of reliability from this phase, it is important that the requirement of reliability is given a score of high importance.
3) We establish a list of specifications that affect at least one or more requirements of the client axis. These characteristics must be measurable and verifiable, and must define the technical performance of the product during its design. They will be deployed in a selective manner in the next phase of the process. In this step, the analysis and evaluation of history existing databases are very useful to identify the main technical characteristics affecting reliability, and that may not be obvious. In the pump - turbine system specifications that have been identified are listed in Figure 2.
4) We identify the interrelationships between customer requirements and specifications. The weight of each relationship can be categorized into three levels where the new note is attributed to a strong relationship, 3 to an average relationship, and 1 low

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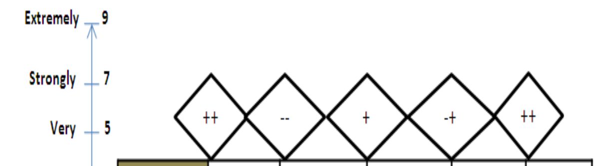
ratio. Each technical feature should be closely linked to at least one requirement, and each requirement must also be related to a technical feature. This ensures that all customer requirements are taken into account in the planning of the product. The weight of each link relative to the wiper system is entered into the matrix of the quality house. We can thus observe that the engine load is one of the technical features that strongly affects the reliability of the system.

5) We develop correlations between technical characteristics and they are indicated in the roof of the house of quality. Specifications may be a positive correlation, which means that the change of a technical feature in one direction affects another feature in the same direction. A negative correlation means the opposite. Four levels of correlation are used, a strongly positive correlation, graphically represented by (++)! Positive (+), Negative (-) and strongly by negative (-). Usually, the correlations add complexity in product design, and result in trade-off decisions in the choice of technical objectives if the correlations are negative. Correlations between technical characteristics of the wiper system appear in the roof of the house of quality, as shown in Figure 2.

6) We calculate the assessment of technical importance. For each technical characteristic data, the values of the index opportunistic customer are multiplied by the corresponding weight matrix. The degree of importance of the technical characteristic is the sum of these products. Importance ratings identify the preferred specifications and therefore indicate the important features that should be selected for further development.

$$IT = \sum\big((\text{Importance coefficient requirement}) * (\text{Technical requirement coefficient})\big) \quad (1)$$



	Important requirement	Number wheels	Motor Torque	Wheel Type	Max engine speed	Min engine speed
High reliability	9	9	3	3	9	3
Low noise	5	1	9	1	3	9
Max flow 65 m³ / h	7	9	3	3	3	3
Manometric maximum 350 m	3	9	3	3	3	3
Yield 60-70%	7	9	3	3	3	5
Technical importance		239	123	83	147	137

Fig.2 Quality home a submersible pump.

In our study of the submerged pump system, the degree of importance of the number of wheels is 9 x 9 x 5 + 1 + 7x9 + 9x3 + 7x9 = 144. The evaluation of the technical characteristics is listed in the row "technical matter", illustrated in Figure 2. Estimates indicate that the number of wheels is an important feature and should be deployed more important in the design process.

3.2 Conceptual Phase.

Commitments made during the conceptual phase are different from those made later: they are often functional, indicating that the behavior of the detailed design should present without specifying how this behavior is achieved, Smith and CLARKSON [8]. At this stage, it is not interested in determining the probability of failure, because in general the information available that calculates the probability at this level of design is poor. Rather, we are interested in reducing the probability reducing modes that lead to system failure.

Smith and CLARKSON [8] distinguish two types of failure that can affect reliability in the design phase, and they give them the name of conceptual failure. Both types of failure are:

- Functional failure, wherein the chosen functions do not meet the purpose of the product. It occurs when the functional specification or requirements developed do not address the whole problem.
- Failure behavior where the behavior produced does not meet the production function associated.

With regard to the failure behavior, a decision taken at the design phase may unnecessarily introduce excessive loads in the product that may be missing in the following phases, and thus cause premature system failure. Therefore, at this stage, we are interested to diminish or even eliminate the functional order to reduce the probability of failure preliminary failures.

The qualitative analysis of preliminary events of failures , the AMDEC and fault tree can be used , based on the decomposition of the main function of selected secondary functions under the concept using block diagram functional , to consider all failure modes likely at this stage of development , in order to deduce the impact on the system (Figure 3).

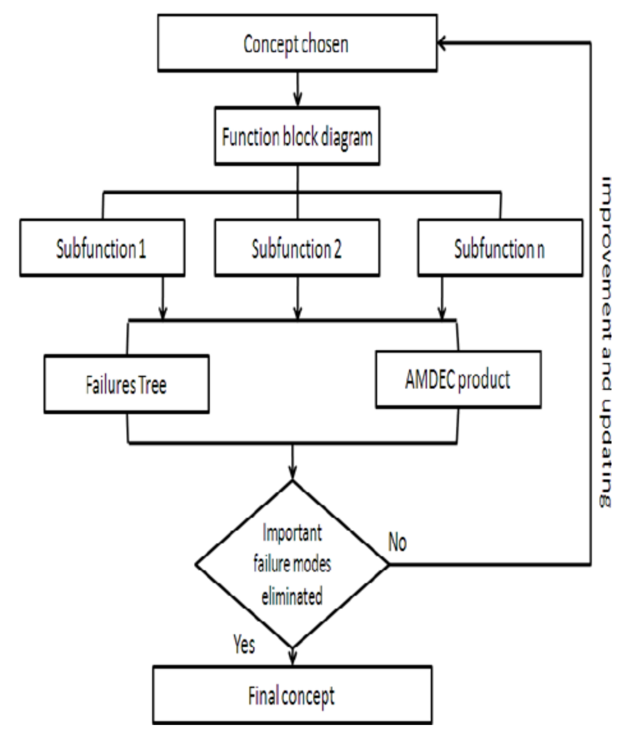


Fig.3: Pre-validation of the concept in the design phase.

This allows us to pre-validate the selected concept before moving on to the next phase. The design effort on the time and knowledge required by the designer will be less important to ensure reliability in steps of architectural design and detailed design, if the final concept developed at the design phase is reliable. This will result in a more reliable and less expensive product, [11].

3.2.1 Application.

In our case study and after the planning phase and identification of needs. We were able to leave the number of wheels have a high score. In the following we are interested in analyzing the wheel (turbine-diffuser).

A. design of the diffuser

At this developmental stage of the design process, the concept is for the broadcaster chooses that of Figure 4.

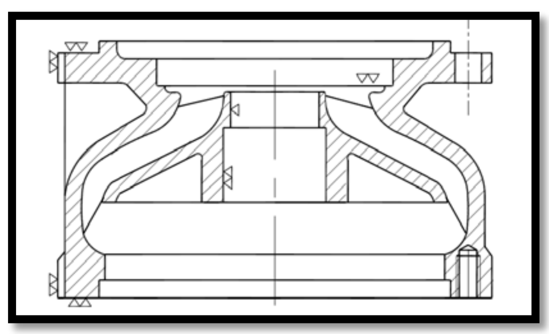


Fig.4 concept chosen for the diffuser

The diffuser is designed to collect the liquid coming out of the wheel, and the direct or to the discharge port, either to the input of the next wheel, depending on whether the pump is single or multistage.

The failure of the overall function, namely "the diffuser does not support pressure. From the figure, we can identify the causes that lead to overall system failure. Either a relationship (OR) with the function overall (Figure 5).

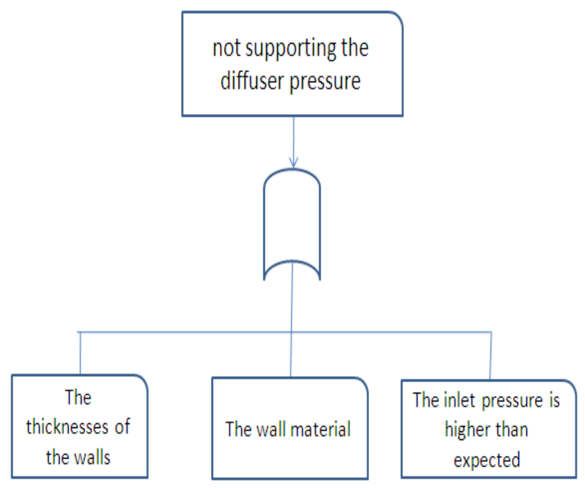


Fig.5 fault tree diffuser.

From Figure 5 and to eliminate the causes of the failures we have adopted the following solutions

- Resize walls broadcasters, while maintaining the same form of hydraulic parts, which determine the values of pressure and height gauge.
- Make materials resistance study that takes into account the material of the walls and the inlet pressure to validate the scaling walls.

Consequently, the concept will be greatly improved and the potential functional failures will be avoided.

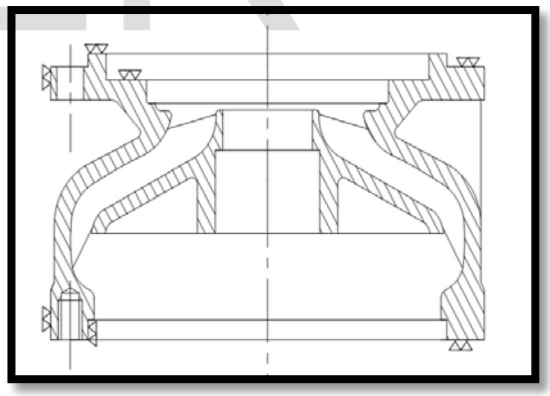


Fig.6 Concept optimized diffuser.

B. Turbine design

The concept chosen for the turbine is that of Figure 7

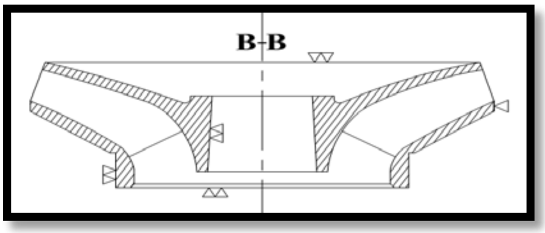


Fig.7 concept chosen for the turbine

The liquid turbine communicates a part of the kinetic energy transmitted by the shaft through its blades (fins). It is mounted on the shaft of the pump by means of a cone and a nut (the method of fixing by adherence).
The failure of the overall function, namely "turbine slides on the shaft of the pump." To eliminate the risk of slippage of the turbine system we replaced the mounting of the turbines, by a fastening system by using obstacle wedges and spacers, instead of fixing by adhesion using whole-cone nut. So the concept will be improved (figure 8).

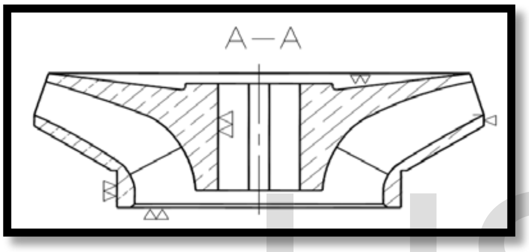


Fig.8 Concept optimized turbine

3.3 Phase architectural

The architectural design is to define the layout of the page preliminary selected in the concept design phase. At this point, the System takes shape, while the initial performance studies are carried out using standard and simplified design rules available to the designer models.
At this point, the interpretation and evaluation of the reliability is based on the probability of failure of components of the subsystem, using the following assessment methods:
- Method static evaluation systems where reliability is assessed without taking into account the time factor. Specifically, the reliability of the components of the system is assumed to be constant.
- Method for dynamic evaluation of the elements where the reliability varies depending on the time.
This type of analysis is generally a form of preliminary or primary analysis.
However, in this type of reliability assessment. We start with a development of reliability that is to represent the system by a diagram; the diagram in turn is composed of blocks from many representatives of subsystem or component [3]. The probability of failure of each of these subsystems, or components is estimated to calculate the probability of system failure.
The implementation of these methods requires a priori knowledge of the components of the subsystems utilized. Otherwise , quantitative qualitative analysis / such as AMDEC or fault tree to identify all the causes of failures as well as their combination is called methods , and specify the dependency between the different causes of failures, and then estimate the probability of system failure (Figure 9).

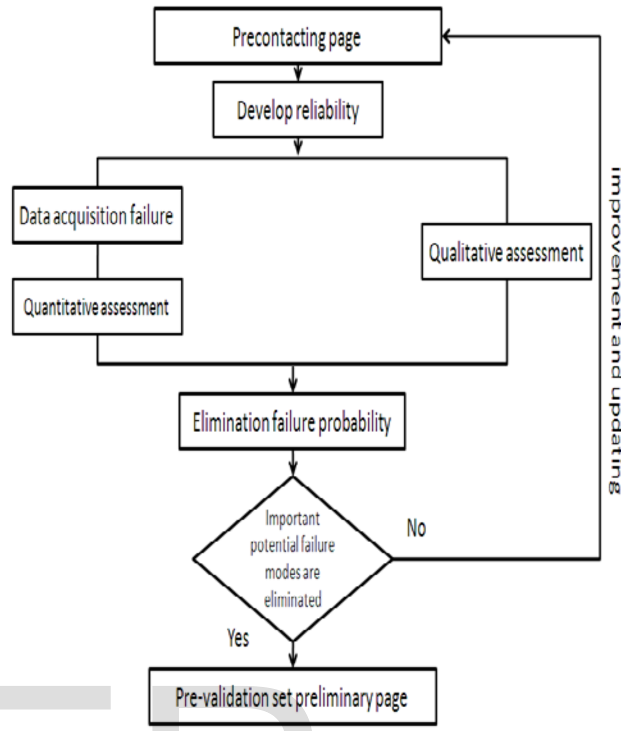


Fig.9: Pre-validation in the architectural phase.

These approaches allow taking into account the size of the system and the logical elements of failure based on either static or dynamic formulation of the qualitative assessment. Therefore, they allow us to validate the configuration of the system, and give us an estimate of reliability, such as the probability of failure, the importance of components, critical components which should make changes in order to improve system reliability.
However, their high level of abstraction is sufficient to connect the variable reliability of the most influential design (eg material properties, stresses, geometry ...) [1].

3.3.1 Application

The main purpose of a reliability study at this stage of design (architectural phase) is to estimate the probability of failure to identify or predict the functional and behavioral failures as soon as possible. Thus, the weak points of the design can be identified and eliminated at this stage.

The system studied (submerged pump) based on the rotation of the fluid to be pumped by circulating in a turning at a speed higher or lower gear. The system consists of an engine, which provides the power required for pumping. Wheel which transmits the power to the water to move (and suck or repress).

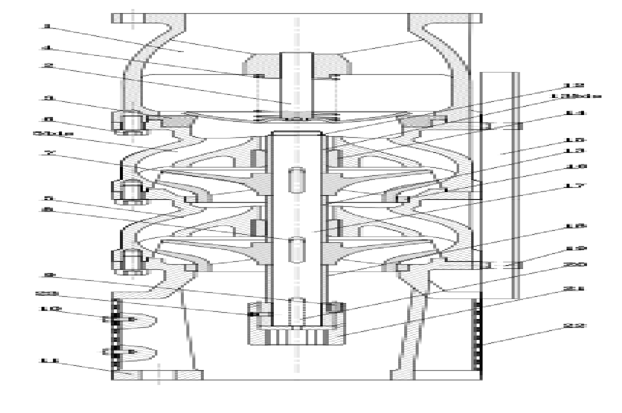


Fig.10 overall plan of the submersible pump

To assess the reliability of the system it is useful to refer to the flowchart shown in figure 9. The main objective of the analysis is to determine the components that are critical to the reliability point of view and to establish a structure of the system reliability.

The elements of reliability are taken separately and their reliability is determined, then a calculation of the reliability of the entire system. The analysis is made with a pre- validation or modification of the preliminary implementation of the system page.

Identifying all system components to consider a system overview (the components and / or interfaces of the component may be considered as components). Some of these components may be defective for a number of reasons.

For the calculation later, it is recommended that consideration of potential failures or specific to a particular item. Each element of the system has a different function, and thus contributes differently to the system reliability.

The system is modeled as a block diagram. This implies that a topological analysis of the prior system to be performed. According to the functional block diagram, we can see that the failure of one component causes the failure of the system, so the system structure is a structure in series (Figure 11).

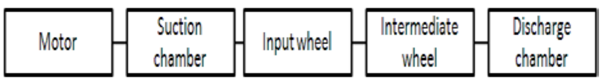


Fig.11: Modeling submersible pump in block diagram.

The reliability R of the system can be calculated for a structure in series, depending on the reliability of the components, the product reliability for all the elements of the system.

$$R_{system} = R_{motor} \cdot R_{Suction\ ch} \cdot R_{Input\ wheel} \cdot R_{Intermediate\ wheel} \cdot R_{Discharge\ ch} \quad (2)$$

The system of equation (2) described in the relevant system reliability and of their functional elements depends. Therefore, it is the actual result of the analysis of the system.

After analyzing the system, it is necessary to determine the behavior of components or their reliability. She and Bert Lechner (1999) proposes as a law associate their failure Weibull distribution whose parameters are shown in Table 1.

TABLE 1

PARAMETERS OF THE LAW OF FAILURE ELEMENTS OF THE SUBMERSIBLE PUMP (WEIBULL OF DISTRIBUTION)

Component		Failure mode	h	b
1	Motor	Motor failure	6.000.000	1
2	Suction chamber	Out of Suction chamber	38.000	1,4
3	Input wheel	Out of input wheels	70.500	1,8
4	Intermediate wheel	Out of intermediate wheels	70.500	1,8
5	Discharge chamber	Out of the discharge chamber	38.000	1,4

The calculation of the reliability of the system is the last step. The reliabilities assigned to each element, are inserted into the equation system (1): the cloud of points is plotted based on Weibull distribution, and using the paper Allan plait. The results obtained are shown on one graph.

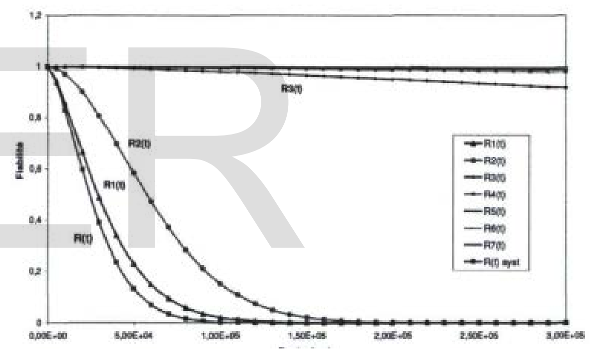


Fig. 12 Graphic presentation of the reliability of the system and its components

It is noted that the curves of the reliability function of components 2 and 3 are prevailing. As a result, the reliability of the system depends on the reliability of the suction chamber and the impeller inlet.

The last step is the analysis of results. If the reliability of the system is believed to be correct with respect to the lists of requirements defined in the planning phase and clarification, the layout of the system is accepted. Otherwise, changes are necessary, namely the first two components to improve the reliability of the system at this stage of development.

In our case the reliability of the system is considered correct.

3.4 Detailed Phase.

Detailed design contributes to the validation and refinement of the preliminary design, the definition of the shapes of components, materials, tolerances, final dimensions; this purpose a companion test is conducted using the experimental design.

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At this stage of design, we begin to assemble several characteristics of each component of the system; these characteristics are the variables (intrinsic and extrinsic) design that characterizes the product.
However, probabilistic approaches to reliability, based on the numerical simulation can be used to design mechanical components in an uncertain environment, and therefore determine the probability of system failure.
These methods use the design variables in the form of probability distributions to reproduce the variability of real systems, unlike those perfect and deterministic which are used in traditional design.
To use such approaches, we need to know the function of system performance that translates the mechanical behavior of the latter. For this, a coupling between the probabilistic approaches and finite element methods, implemented is performed using CAD software (ABAQUS, CATIA ...) while leveraging the existing model. This coupling allows the probabilistic model to define the random achievements to be considered in the mechanical model data to assess the reliability of the system.
The main steps that allow us to calculate the probability of failure at this stage of development, and therefore allow us to assess the reliability of the system are:
- Preliminary analysis of the system under study: this part is to collect various information about the product needed to address a reliability assessment (intrinsic and extrinsic variables). Then, a qualitative study of failure modes using predictive analysis methods (AMEC, failure tree).
- Mechanical Analysis (ABA) : this analysis is to define a choice of mechanical model , by associating with each failure mode (fatigue, fracture mechanics , ...) a mechanical model which reflects the behavior of the candidate for evaluating reliability (current earlier stages) at different failure scenarios , depending on the design variables . At this stage, we used the finite element method to construct the mechanical model (where we do not have exact analytical formulas and simple to build this model). Next, a formulation of the boundary which characterizes the behavior of the resistance load relative to the state function is performed.
- Evaluation of variability of design parameters: the design variables are generally random in nature. In this step the probabilistic approach , the pilot design variables Code finite element methods (FEM), according to the statistical distribution (probability density distribution function), which take account of their dispersions and mechanical variability , to model the uncertain context of the mechanical model and ensure a reliable design .
- The calculation of the probability of failure using approximation methods FORM / SORM, or the methods by Monte Carlo simulation.
- The sensitivity of the geometric variables: this step is to identify the weight of each variable in the calculation of default probabilities and examine those most influential on default and the life of the product.
- Analysis of results: The results obtained allow or pre-validation of the system if it meets the requirements set by the customer, or to make changes at critical elements to improve the probability of failure system, and work towards an acceptable solution at this stage of development (figure 13).

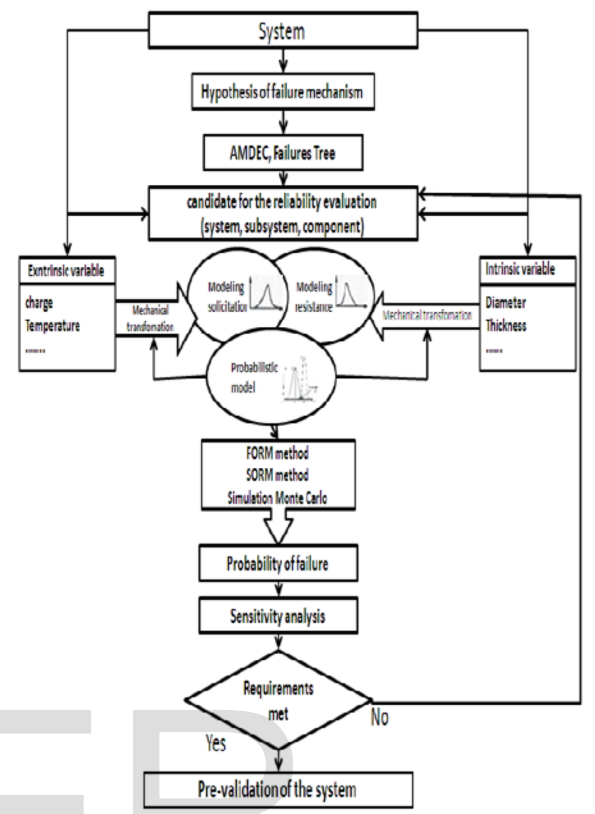

Fig13 Pre - validation in the detailed stage

Multiple interfaces of software reliability assessment, and commercial finite element analysis program used to perform this coupling mechanical reliability engineer. However the use of these interfaces, which are still in the process of improvement, is limited to the research laboratory.
To understand the main steps developed for this design phase, namely, probabilistic analysis and its coupling with finite element methods, in the need to determine the limit state function of the system in case we have no analytical formula: a study is performed using examples from the literature on a computer code FERUM (Finite Element Reliabiliy Using Matlab) whose first development began in 1999 at the University of California at Berkeley (UCB). This code consists of a box open-source MATLAB tool, with different reliability assessment methods.

4. Conclusion

The problem of reliability in design is still very complex to deal with; this is due to lack of available data at this stage of development and the imprecision of variables and design parameters. To approach this problem, a method of taking account of the reliability has been developed.

The developed methodology includes different tasks to be implemented in the design process, using the procedures to be performed in each phase. These procedures can be considered conceptual processes that pave the way for research in the field of reliability design for:

- Ensuring the reliability of products throughout the design process.
- Improve design decisions reliability point of view.
- Allow pre-validation in the early stages of the design process.

At the end of the work of this paper, several prospects are emerging. The main extensions proposed are the following:

- Integration of Bayesian (conditional probability) approach to estimate the reliability at each stage of the design process.
- Integration of validation methodology of reliability software of Computer Aided Design.

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